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NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION 1984 REVIEW AND 1985 WORK PROGRAM

Report No 85-20-K

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ABSTRACT

The projects and achievements of the Nondestructive and Fracture Evaluation Section in 1984 are reviewed. Proposed projects and objectives for 1985 are described in outline.

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MR. F.J. KEE
Director of Research

NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION
1984 REVIEW AND 1985 WORK PROGRAM

I - INTRODUCTION

The disciplines represented by the two Units that comprise the Section are quite different yet history shows that when significant events occur related to material or structural performance, both units play an important and complimentary role. In 1984 this was well demonstrated in the substantial amount of work related to the Pickering Unit 2, G16 failure and the potential repercussions arising from it. The Section responded to the needs of the Corporation to its utmost capability. This meant that, at times, it was necessary to step outside of our "mission" of research and development but, more noticeably, it meant that the actual work program undertaken bore little relationship to the 1984 plan which was set before 1 August 1983, the date of the G16 failure.

Of the actual 1984 work program, 90% was in support of our Nuclear Program. The year started with continuation of work on the CIGARette inspection system plus site support to CNS at Pickering then gradually evolved and matured into the development of finite element models of stress field associated with blisters and the refinement of ultrasonic techniques to detect and map these defects. In all, our internal clients supported 63% of our program to a sum of K$1331.

A brief description of the interests of the Nondestructive Evaluation Unit and Fracture Mechanics Unit follows:

Fracture Mechanics Unit

Unit Head - Fracture Mechanics:	Dr. B. Mukherjee
Engineers:	Mr. M.L. Vanderglas Dr. Y.J. Kim Mr. A. Wallace
Technologists:	Mr. D.W. Carpenter Mr. C.P. Stearns Mr. D.M. McCluskey

The objectives of the Unit are:

- Assess the impact of flaws and off-design operation on the reliability and safety of major plant components.
- Propose and evaluate new methodology for flaw-structure interaction analysis that will quantify the real margins of safety of pressure bearing components.
- Improve quantitative understanding of the effects of plant chemistries, materials and fabrication processes and stress state on performance of major plant components.

The main research interests of the Unit are:

- Research into experimental and computational aspects of fracture mechanics.
- Determination of fatigue and fracture properties of generating plant and transmission system materials under operating environmental conditions.
- Investigation of techniques for service life prediction of components.
- Development of new fracture mechanics analysis procedures where conventional techniques are inappropriate.
- Development of rapid structural integrity evaluation methods to meet jurisdictional requirements.

Nondestructive Evaluation Unit

Unit Head - Nondestructive Evaluation:	Dr. M.P. Dolbey
Engineers:	Mr. W.K. Chan Mr. E.G. de Buda Mr. D.W. Donnelly Dr. M.D.C. Moles Mr. J.H. Sedo* Mr. S. Buhay** Dr. G. Jarvis**
Technologists:	Mr. R.S. Algera Mr. E. Bernacchia Mr. B. Antonacci
Technicians:	Mr. A.L. Allen Mr. J.R. Boon Mr. G.E. Truemner* Mr. R. Ginzel* Mr. S. Holver*

The objectives and principal research interests of the Unit are:

- Design and development of remotely operated, electromechanical scanning system for nondestructive examination of nuclear station components to reduce man-rem expenditure and improve inspection reliability.

- Evaluation of new concepts and development of equipment to enable remote and precise spatial measurements in nuclear power stations.

- Research into limitations of and applicability of nondestructive testing techniques for defect detection and evaluation, particularly with regard to nuclear periodic inspection requirements.

- Development of new nondestructive techniques and procedures for particular applications at generating plants and transmission systems.

- Investigation of signal analysis methods for improved defect characterization.

- Assistance to the Operations Group with non-routine inspection problems, major system breakdowns, and service inspection requirements.

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* Contract Employees
** On attachment from CNS

II - 1984 WORK PROGRAM REVIEW

1.0 FRACTURE MECHANICS RESEARCH AND APPLICATION

The overall goals of the Fracture Mechanics Unit are to improve our understanding of material response due to various stress states and to apply fracture mechanics to address practical issues related to material selection, design and structural integrity evaluation. The review of the 1984 work program is organized to bring in focus the work done by the Unit in these two areas. Subsection 1.1 contains summaries of projects related to materials used by Ontario Hydro. Subsection 1.2 describes work related to the application of fracture mechanics to assess the integrity of various power plant components.

The transfer funded component of the Unit's work has increased from 32% of the Unit's total expenses in 1983 to approximately 50% of its expenses in 1984. Most of this increase has been in analytical fracture mechanics. As a result, the Unit was unable to pursue transfer funded longer term developmental work in elastic plastic fracture mechanics and linear elastic fracture mechanics. On the positive side, we have experienced a shift in demand from a large number of quick and superficial analytical projects to a relatively few longer term projects which require an extensive and in-depth treatment of the subject.

1.1 Plant Materials - Test Program

Comparison of Zircaloy-2 Pressure Tube Burst Test With Curved Double Torsion Results

Curved double torsion specimens were used to determine the room temperature fracture toughness of a Zircaloy-2 pressure tube section which was hydrided under reactor operating stress to 70 to 80 ppm hydrogen. The results showed that the fracture toughness varied around the circumference and along the length of the tube because of variation in hydride morphology. The change in fracture toughness as a function of Hydride Continuity Coefficient (HCC is a measure of the 'continuous' hydride path through the wall thickness) in the specimen was studied. The presence of radial and partly reoriented hydrides lowered the fracture toughness. The fracture toughness determined from the slit burst test was within the scatter band of the double torsion specimens which had a similar hydride morphology as the burst tube defect. The test results also indicated that the stress intensity at crack initiation was relatively independent of the extent of hydride reorientation which suggests that crack initiation may be governed by the presence of any radial hydrides at the crack front. (Ref OH Report 84-392-K).

Curved Double Torsion Fracture Toughness Tests Round Robin II on Zr-2.5% Nb Tube 1804-92B (Mixed Hydrides)

Room temperature fracture toughness tests were carried out on a segment of Zr-2.5% Nb pressure tube 1804-92B. The tube segment was supplied by CRNL for Round Robin II. It contained a mixed hydride morphology with both circumferential and radial hydrides. All specimens exhibited significant crack jumping prior to fast fracture. The toughness behaviour of the specimens was confirmed by metallographic and fractographic examination of the specimens. (Ref OH Report M84-16-K).

Application of Tearing Modulus to Piping Analysis

Because of the cost and difficulty of providing pipe whip restraints at some locations of the Darlington PHT piping circuits, a joint project between Mechanical Design, D&D and Research was initiated to endeavour to demonstrate the safety of the system using a relatively new approach. Our involvement in the work has been limited to the development of test methods to obtain the requisite J-T resistance curves. An automated system was developed, capable of testing two specimen types, at room and elevated temperatures. A number of tests were performed to "fine tune" both the system and specimen design in order to generate reproducible results.

Fracture Toughness of Temper Bead Repair Welds

In co-operation with the Welding Unit, fracture toughness measurements in the heat-affected zone (HAZ) of A516-70 temper-bead welds were performed. The objective of the project was to generate HAZ toughness data for integrity assessments of repair welds using non-post weld heat treated temper-bead welds.

Three-point bending specimens (10 x 20 x 90 mm), taken from two orientations of HAZ as well as base metal were tested following the ASTM E813. The tests were performed in the temperature range of -40° to 280°C. Low temperature tests were performed in a specially built environmental chamber while high temperature tests were performed in an electric furnace. The J_{Ic} fracture toughness test results showed that the HAZ produced by the temper-bead weld repairs exhibit equivalent or greater fracture toughness than the base metal. Metallographic examination of the weld repair shows that the temper-bead technique can produce a grain refined HAZ microstucture with acceptable hardness values. (Ref OH Report 84-413-K).

ASTM Round Robin on Crack Arrest Testing

A proposed ASTM Test method for Crack Arrest Toughness of Ferritic Materials has been developed by the ASTM E24 Committee on Fracture. A round robin on crack arrest testing is currently in progress and the Fracture Mechanics Unit is participating in the test program. The program will involve testing 5 x 20 x 20 cm test specimens of A533 B pressure vessel steel and A514 and A588 bridge steels. In the first two tests on A514 steel, the running crack did not arrest. In a related program 7075-T6 aluminum alloy was utilized to determine the effect of specimen size on crack arrest toughness values and to investigate the feasibility of using subsize specimens for measuring crack arrest toughness. Eleven specimens out of a toal of fourteen tests showed a successful run-arrest event. It appears that a run arrest event can be produced in high strength aluminum alloys using specimens which are as small as 0.6 x 6 x 6 cm.

Cast Iron Spent Fuel Shipping Container Design and Material Requirement

Material requirement and design criteria for preventing brittle fracture in nodular cast iron spent fuel shipping contianers were assessed. The purpose of this work was to review the material properties and design criteria which are relevant to the fracture prevention of nodular cast iron shipping containers.

In this project, a series of fracture mechanics analyses were performed to provide a quantitative basis for assessing the margin of safety inherent to a particular cask. It was demonstrated through a linear elastic fracture mechanics (LEFM) procedure that a proposed shipping cask design, of the candidate nodular cast iron material, can withstand a nine-meter drop test. No crack initiation would occur even if a flaw of a size well above the detection limit of conventional nondestructive examination existed in the cask. The fracture toughness of nodular cast iron is sufficient to ensure the structural integrity of these casks.

Future work that will be required to qualify cast iron shipping containers for Canadian use has been recommended. (Ref OH Report 84-376-K).

Steam Generator Tubes Containing Part-Through Fatigue Cracks

Several specimens containing part-through fatigue cracks were produced for use as 'standards' to calibrate eddy current inspection equipment. A 0.1 mm deep starter notch was used to initiate the fatigue crack. The method was successful in producing part-through cracks in thin (t $\sim$ 1 mm) tubes. A correlation between crack depth and surface length could not be found. Therefore, the crack depths of the calibration specimens were not known accurately. (Ref OH Report M84-43-K)

ASTM, CEA and Other Miscellaneous Activities

Various members of the Unit participated in the activities of the following committees and task groups:

1. ASTM E-24 committee on Fracture.

2. Montior for a CEA project on Fracture.

3. A National Research Council Committee organized by the NRC-Institute of Materials Research to determine the extent to which Canadian Industries are affected by ductile fracture.

4. International Cyclic Crack Growth Rate Group. This group has been an invaluable source of information regarding current research on the effect of pressurized water reactor environment on fatigue crack growth rate in pressure vessel steel.

5. Secretary to the Canadian Committee for Research on the Strength and Fracture of Materials. The objective of the committee is to support and encourage fracture related conferences, seminars and workshops in Canada.

6. Guidance, support and assistance was provided to a University of Toronto student who is working on her final year thesis with the Fracture Mechanics Unit.

1.2 Application of Fracture Mechanics

Stress Intensity Factor for Single External Axial Part-Through Defects in Pressure Tubes

Stress Intensity factors (SIF) for hypothetical single external axial part-through defects at outlet ends of PNGS A Unit 1 and 2 pressure tubes were calculated. The applied SIF ahead of the final part-through defect in P2 G16 was estimated and the significance of the result in terms of possible sub-critical crack growth mechanisms prior to tube rupture was discussed. (Ref OH Report M84-7-K).

Structural Integrity Evaluation of Bruce A PHT Pump Flywheel Keyways

A stress and fracture analysis was completed to provide inspection requirements for Bruce A PHT pump flywheel keyways.

Initially, estimates were made based on some approximate results given in the literature. Subsequently, finite element stress analysis was used to identify likely crack initiation sites. An elastic plastic analysis revealed that, at rest, the keyway regions would be subjected to localized compressive residual stresses. Having identified the keyway radius as the most highly stressed region, the finite element

method was employed to compute stress intensity factors for a range of crack lengths emanating from the radius. Results indicated that the initial estimates were adequate with the net conclusion that a 7.6 mm crack must be detectible.

ASME Section XI Analysis of Multiple Defects

An ASME Code Section XI analysis of a large number of indications in a Pickering boiler upper manway weld was performed. The distribution of the membrane and brending stresses acting normal to the defects due to bolt loads, internal pressure, maximum thermal transient and worst case pipe reactions were utilized. Analysis of the growth of the defects due to cyclic loading was performed numerically using a computer program developed specifically for the manway defect assessment. The program treats all the indications simultaneously in order to account for their changing interaction during growth. The computer program was utilized to evaluate the 1984 inservice inspection results from the Pickering 3 Boiler 6 manway welds. The computer program will be utilized to evaluate subsequent inspection results from the same manway. (Ref OH Report M84-102-K and M84-103-K).

Stress Analysis of Pressure Tube Hydride Blister

Hydride blisters have recently been observed in several Pickering 'A' Zircaloy-2 pressure tubes. The presence of blisters on the outside surface of the pressure tube was one of the factors which may have led to the rapid failure of tube G16 in Pickering Unit 2 in August, 1983.

A stress analysis of pressure tubes was performed to study stresses produced by volume expansion associated with the precipitation of zirconium hydrides in a zirconium matrix in the form of "blisters". Analyses were performed based on various levels of approximation ranging from exact elastic to nonlinear finite element models. Parametric studies were used because the physical properties near the blister were not clearly defined at this stage.

Preliminary results based on this model indicate:

i. Significant stresses can arise from volume expansion of hydride blisters, being largely compressive within the blister, tensile outside.

ii. Expansion stresses decay to zero within about one wall thickness away from a blister.

iii. Highest stresses are developed under the blister, at the deepest point.

iv. The magnitude of stresses is strongly influenced by the exact distribution of precipitated hydride concentration (which is presently unknown).

v. The peak expansion stresses appear to increase more quickly with the ratio of blister diameter to depth than with depth alone.

(Ref OH Report 84-175-H).

Fatigue Evaluation of Bruce NGS'A' End Ring

A fatigue life estimation of Bruce NGS'A' generator end ring was performed. For the purpose of the analysis it was assumed that a sharp fatigue crack exists in the bayonet lug radius of a generator end ring. The estimation was based on fatigue crack growth data generated in a dry hydrogen environment and high frequency test conditions. Starting from several assumed initial flaw sizes, the remaining cyclic life of end rings was calculated. This information when coupled with appropriate safety factors and inservice inspection results may be utilized to set an appropriate inspection interval to prevent an end ring failure. (Ref OH Report M85-2-K).

2.0 INSPECTION SYSTEMS DEVELOPMENT AND APPLICATIONS

2.1 CIGAR (Channel Inspection and Gauging Apparatus for Reactors)

The characteristics of the CIGAR system have changed somewhat over the past year as the system has evolved. Several hardware changes and additions have been made to improve performance and a new remotely controlled camera is currently being mounted on the rig. The software that drives the CIGAR inspection head through the pressure tube is essentially complete when compared to the original design specifications, however, recent experience has shown that some revisions to these specifications, and software, may be desirable for additional performance improvements.

The data acquisition and playback systems have also gone through considerable evolution during the past 12 months. These systems are in the following states.

Gauging

This system is complete and has undergone tests which have demonstrated that both the accuracy and repeatability of the wall thickness measurements are satisfactory. Further tests will be required to verify the accuracy of the pressure tube diameter measurements.

Flaw Detection

The flaw detection data acquisition and playback software is complete except for some minor tuning of control parameters. The system was put through extensive, though not exhaustive, tests which demonstrated that the detailed scans operated too slowly. The acquisition and playback software has now been modified to accommodate a much faster detailed scan but the drive software must still be re-written to produce this.

Gap

The CIGAR gap system is fully operational and has benefited from experience gained in the CIGARette inspections. Initial tests looked promising but recently, a location in the fuel channel mockup has been found that yields results that are repeatable but not completely satisfactory. Work is currently underway to discover the causes of these unsatisfactory results and to determine if they can be improved.

Sag

Over the past year, new electronics have been developed for the sag system which significantly reduces the system's sensitivity to water path shunting between the wires of the inclinometer. The signal line is sampled between power pulses to minimize the effect of any current leaking from the supply lines into the signal line. Though the prototype has been tested, full sag system tests will not be performed until the final version of the electronics have been constructed in mid January 1985.

Garter Spring

While a garter spring location coil has not yet been integrated with the reference design CIGAR system, most of the preparatory work has been done. It has been proven that the garter spring location coil will function properly when mounted around the sag module on the CIGAR inspection head. An in-channel multiplexer has been developed which will allow the garter spring coil to share the signal wires already installed for use by other data acquisition systems.

Multiplexer

A sixteen channel, radiation resistant signal multiplexer has been developed to fit inside a foot module in the CIGAR inspection head. Six of the fifteen CIGAR signal wires are used. Two lines provide switching while the remaining four carry signals. This device has been successfully tested in pH10 lithium hydroxide solution at 50^{o}C and is ready to be built into an inspection head. The mutiplexer is needed to accommodate the additional signal wires required by the

garter spring detection coil. The electro-magnetically actuated reed switches in the multiplexer can be used to connect various inspection systems to the four signal coaxial wires.

2.2 Pickering NGSA - CIGARette - Pressure Tube Inspection

Assistance was provided to CNS and Pickering A during the inspection of some 50 pressure tubes in Units 1 and 2 in late 1983 and early 1984, in the following areas.

Inspection Head Supply and Maintenance

The procurement, assembly and testing of 6 new inpection heads was co-ordinated. Also, maintenance and probe replacement on used inspection heads was provided on site.

Rod End Connectors and Cables

The rod end connector and cable were redesigned to provide cable strain relief and to incorporate a "0" rotational position device. Twelve of the new units were manufactured and supplied to site. Also twelve sets of all other cables between the CIGARette unit and control console were provided.

Containment Penetrations

Leak tight penetrations that allowed the cables for two inspection systems to pass through an existing pipe into the containment building were designed and procured by the Unit. They allowed the control and inspection consoles to be placed outside containment. A savings in time and man-rem resulted as well as providing much greater flexibility for inspection personnel.

Gap Measurement

The percentage of channels where good gap results were obtained increased steadily during the Unit 1 and 2 inspection program. The improvement was due to a number of factors including familiarity with the system, refinement of the procedures, improved troubleshooting of the equipment and the availability of tested spare sub assemblies. A number of remaining problem areas affecting system reliability have been identified and some are currently being worked on. These include, in-channel operational checks to improve troubleshooting procedures and an automated wall thickness measurement system which will increase the number of data points that can be collected and help to properly align the ultrasonic and eddy current data. In addition, an examination of the technique is currently being performed for the CIGAR project where results can be studied without interference from equipment problems.

Garter Spring Detection

The design of the eddy current probes initially installed in the CIGARette systems was a modification of that used to successfully locate the garter springs of channel P2-J15 in September of 1983. Early this year, these probes were replaced with send receive probes designed by CRNL which produced results with a much better signal to noise ratio.

Ultrasonic Inspection

During the early part of the year, continued assistance was given to CNS on the CIGARette inspection of Pickering Units 1 and 2. While the ultrasonic flaw detection continued to work well, the ultrasonic wall thickness measurements using the CL204 instruments were unsatisfactory in service conditions. Work is underway to improve this sytem.

UT Playback System

Development of a computerized automated ultrasonic flaw detection playback system, modelled after that developed for CIGAR, was completed and delivered to CNS in early February. It was used extensively for generating isometric amplitude position plots of the Pickering 1 and 2 inspection data for full evaluation.

Preparations for CIGARette at Bruce NGSA

In preparation for possible CIGARette inspections at Bruce NGSA, an improved wall thickness measurement system is being developed and the procurement of a cable penetration is being investigated.

2.3 NILOCS-NIMOCC

A Research Division program has been established to develop systems for the Non-Invasive Location of Channel Spacers (NILOCS) and the Non-Invasive Monitoring of Channel Condition (NIMOCC). The program is being jointly supported by Research, TTSD and Design and Development and employs the expertise of a number of groups within Research Division. The program is being administered by M. Dolbey of the NDE Unit.

A number of concepts for achieving NILOCS are being investigated. Acoustic Emission source location methods show promise if a means of getting all spacers to tap reliably can be achieved. However, discrete tapping of the spacers rather than continuous buzzing is required and the excitation should not cause the spacers to move out of position. Excitation methods studied to date do not meet all these objectives.

The use of generalized cross correlation (GCC) signal processing techniques for analyzing acoustic energy generated by tapping or buzzing spacers is being studied. These techniques have the potential for being able to locate the position of weak coherent sources, such as spacer generated noise, in a noisy environment. The complex geometry of the fuel channel creates problems such as multiple signal paths. Methods of overcoming these problems are being studied.

Vibration monitoring techniques are being investigated. A thorough study of the structural dynamics of fuel channels was carried out with computer models for both low frequency bending modes and high frequency shell modes being developed. Extensive modal testing of the Bruce Mockup channel were performed and used to tune the computer models. Predictions of the effects of structural changes, including spacer movement, were then made. Recently, vibration signatures have been collected on all channels of Bruce Unit 5 and an analysis of the stability of signals has been carried out.

A study was made to determine the feasibility of locating channel spacers from the outside of the calandria tubes with a robotic crawler put into the calandria through an overpressure duct. The method appears feasible but would require a lot of development to assure the degree of reliability required.

A search for other concepts was made. A request for proposal was sent to more than 30 universities and research institutions. Two proposals were received. After evaluation, it was decided not to act on them at this time.

2.4 New Business Ventures -CIRENE

The Italian goverment's agency for alternative energy (ENEA) are building a demonstration scale heavy water moderated pressure tube reactor. They have expressed an interest in purchasing pressure tube inspection equipment and technology from Ontario Hydro. A contract to review their plans for a drive mechanism to move the inspection head through the channel was established. A member of the NDE Unit and an engineer from CGE reviewed their design and visited the site and equipment manufacturers in Italy.

Assistance is being provided to NBV in arranging to provide the inspection systems.

2.5 Automated Scanning Systems For Ultrasonic Inspection

Robotic Scanning System

A robotic control software system (RCSS) was written to provide a programmable computerized control system that can run on an IBM PC/XT or compatible computer and drive a Unimate PUMA six axis robot. RCSS

provides the programmer with the capability of driving the robot through a complex set of motions which may be computed in real time, thus allowing the robot to respond to a changing environment.

The next step in this part of the NDE unit's robotics program will be to provide the controlling PC with feedback directly from the robot or from some type of proximity sensor connected to the robot hand. With this feedback information, the robot will be used to "feel" the shape of a vessel, plate, or other object. This shape will be recorded by the PC and an ultrasonic or eddy current probe will then be automatically scanned over the object. In this way, a full non-destructive inspection of complex and arbitrarily shaped object may be carried out with a minimal amount of operator intervention or exposure to a harsh inspection environment.

Robotic Ultrasonic System Development

Substantial improvements have been made to the Apple computer based robotic UT scanning system. A spring-loaded, gimbal probe mount was added to allow contact inspection rather than using an immersion tank. Software was added to reduce the setup time. It is now no longer necessary to go through the tedious process of teaching a series of points to the robot by manually positioning the arm. Instead, a few numbers describing radii of curvature and extent of scan are fed into the computer. The computer calculates the appropriate coordinates along the surface and transmits these to the robot. This makes it easy to set up the robot to scan cylindrical, spherical, and ellipsoidal surfaces as well as flat surfaces. This system was used to inspect a series of curved steel plates from a Bruce HWP tower.

Robotic Inspection

Work continues on developing an inspection procedure for titanium diffusion bonds using a commercial robot to demonstrate in-service capability. A waterjet manipulated by the robot has been used to inspect a bonded ring, using manual control. The robot is being interfaced to the IBM-compatible computers to be able to perform conventional ultrasonic C-scans.

Laboratory Automated Scanning Systems

System development was primarily in the area of software development. This took the form of improvements to existing software for increasing capabilities and making the system more user friendly. Among the most useful software developed was an eight gate C-scan which allows up to four different probes to be used simultaneously. This scan was used with the CIGAR head on the CANDEV pressure tube. It is also expected that this softwre will provide a final solution to problems previously found with distance coded C-scan. Component wise, the system has been duplicated so it is now possible to run two independent tests simultaneously.

3.0 NDE TECHNIQUES R&D AND APPLICATIONS

3.1 Acoustic Emission Techniques

Acoustic Emission Testing of Lakeview GS Economizer Inlet Header

The occurrence of stub tube failures in a Lakeview GS economizer inlet header resulted in a need for inspection, monitoring and evaluating the integrity of headers in thermal power plants on an ongoing basis.

A potential technique for continuously monitoring the headers to detect crack growth and leaks as they occur is acoustic emission testing. OHRD, along with Viatec Resource Systems Inc and the University of Manitoba, have instituted a program to apply acoustic emission testing techniques to the headers.

This work consists of gathering background acoustic emission signals from the header, performing attenuation tests on the header material, the design of a continuous AE monitoring system by Viatec Resource Systems, and material testing by the University of Manitoba. This work is still in progress with the recent installation of Viatec's prototype AE monitor at Lakeview.

Acoustic Emission on Bruce Unit 2 Turbine Generator

The turbine generator at Bruce NGS A, Unit 2 came to an unexpected stop while running on turning gear. Station personnel isolated the problem to the high pressure and the first stage low pressure turbines.

An acoustic emission testing technique was applied to monitor for impacts when the two turbine stages were rotated. On both occasions when the turbine was rotated until it stopped, impact type acoustic emissions were detected in the HP stage. The station maintenance staff removed the cover on the HP turbine stage and discovered a broken coupling bolt which was preventing rotation.

TWE - Acoustic Emission Testing of Hydraulic Cylinder

A hydraulic cylinder on a manlift device failed explosively along an axial weld causing injury to the operator. Subsequently, four others were found to contain multiple defects. A burst test to failure of one of these required very high pressure and the cylinder failed at the end cap instead of the axial weld. Acoustic emission monitoring was employed to predict imminent failure and the location of the source of failure. A second cylinder was monitored. This cyliner contained multiple defects along the axial weld and was expected to fail in this area. A loading technique similar to operating conditions was implemented and the cylinder loaded several times.

Each loading started at zero and went to a progressively higher load level until failure occurred. A report has been issued describing the loading technique and detailing the acoustic emission results.

3.2 Ultrasonic Testing

Pickering A Ultrasonic Blister Inspections of Pressure Tubes

In February, two blistered pressure tubes from Pickering 1 (G14 and K05) were reinspected at CRNL. The inspections used a variety of laboratory techniques, and showed, for example, that pitch-catch scans could be used to differentiate blisters from other reflectors. Also, blisters could probably be monitored using small-scale C-scans. A number of laboratory-grown blisters were inspected later. Zr II blisters, grown using a SPEL contact technique, appeared similar to service blisters, though more regular. In contrast, Zr-Nb blisters grown using an airjet, were very poor reflectors. Metallography showed the Zr-II blister to be cracked, whereas the Zr-Nb blisters were not.

CNS - Ultrasonic Calibration for CIGAR/CIGAReete

A report describing the philosophy behind the CIGARette "grass-level plus" approach has been drafted. The pros and cons of the power check and ASME-type notch calibration procedures were outlined. An experimental program was undertaken, comparing power checks with various reference notches and other reflectors using different ultrasonic probes, flaw detectors and cable lengths. Though the signal amplitudes from the reference notches and power checks varied with the test conditions, the power checks remained at a consistent dB difference from the notches. This indicates that the power check calibration approach is valid. The results also showed that typical CIGARette scanning levels were well below manufacturer's inspection levels.

CNS - Ultrasonics Flaw Detection Test - CIGAR

A pressure tube section, containing 48 manufacturing-type implanted defects and loaned by CRNL, was tested on the CIGAR rig in December. After minor problems, including removal of air bubbles, the general helical scan worked well. All 24 outside surface defects were easily detected, plus a number of other visible marks. Unfortunately the tube was fairly "noisy" so sensitivity levels were well below that of normal CIGARette inspections. The detailed helical scans proved to be far too slow for service use, and modifications are being investigated.

SLAR - Fast Scan Blister Detection

An ultrasonic fast-scan blister detection probe is being developed for SLAR. It will allow cracked blisters anywhere in the bottom 60^{o} of a pressure tube to be detected during a single pass. The first prototype was reasonable, but there was a considerable variation between various segments. The second prototype's segments are more evenly matched. The probe appears to be capable of detecting cracked blisters, but not garter spring marks or oxide patches. Anticipated further work includes evaluating production batch of segments, testing wider probes, and development of a calibration procedure.

SLAR - UT Wall Thickness Measurement

SLAR intends to employ eddy current gap measurement systems to provide feedback during spacer unpinching operations and to provide gap profile information of the post-SLARed channel for analysis. An accurate independent measurement of pressure tube wall thickness is required to calculate the gap from the eddy current information. As currently conceived, the SLAR head will require 4 separate gap measurements and therefore, wall thickness measurement systems. A system using a single ultrasonic thickness gauge and multiplexed remote pulser preamplifier has been designed and the instruments are being purchased.

Pickering A - Manway Contact Focussed Probe

A large focussed probe, tailored to steam generator manway specifications has been delivered and tested at Research. The probe was made by a local manufacturer using specifications provided by a CRNL computer program. The contact focussed probe was significantly better than the previous immersion system, though the beam focussed too short and spread significantly in a circumferential direction. Further work on these probes is being undertaken.

Nanticoke - Turbine Blade Cracking

After cracking was discovered in the fir tree roots on LP turbine blades, a contact ultrasonic technique was developed to detect cracking without removing the blades from the turbine disk. However, there was a noticeable variation in blade manufactured contour, so the contact probe shoe developed only fit a few blades. An immersion system would probably be better.

High Frequency Ultrasonics

Work continued on a project using high frequency ultrasonics to estimate hydride platelet concentration using attenuation measurements. A University of Toronto student worked on two pressure

tube specimens containing varied concentrations of platelets. However, the 100 MHz ultrasonic probes did not operate much above 33 MHz, and the results to date have been inconclusive.

An ElectroMagnetic Acoustic Transducer (EMAT) for Measuring Boiler Tube Wall Thickness

A Canadian Electrical Association contract, won by the UKAEA Harwell, to develop an EMAT or non-contact transducer for scaled boiler tubes was monitored. A prototype device, tested at Lakeview and Nanticoke proved successful, and a second improved prototype has been proposed.

Remote Inspection of Used Fuel Containers

Inspection of the final closure weld of used nuclear fuel containers requires a knowledge of candidate material weld metal properties.

Longitudinal wave beam skewing measurements were performed on welds of stainless steel, copper, Hastelloy C-276, Inconel 625, titanium grades 2 and 12 and mild steel. The titanium and mild steel showed negligible beam skewing, but the other materials showed significant beam skewing. Beam skewing/anisotropy will probably present major inspection problems for some materials.

Miscellaneous Ultrasonic Consultations

During 1984 consultation was provided as follows:

CNS - Verbal information on magnetic particle and dye penetrant systems, wedge material for ultrasonic transducers, UT instrument stability, and ultrasonic systems for bolt elongation. Experimental ultrasonics on cracked turbine bolts, and crack detection in turbine disks.

CTS - probe selection and instrument capabilities.

Mechanical Research Department - ultrasonic techniques for inspection of new strongfloors, ultrasonic thickness measurements for chemical machining of steam genertor tubes, and ultrasonic detection of water level in pipes and vessels.

Chemical Research Department - ultrasonic thickness measurements on molography test samples.

Civil Research Department - Advice on differentiation of c and p waves for concrete UT transducers.

Electrical Research Department - flaw detection in polyimide material and ultrasonics for rolled joint integrity.

Metallurgical Services - flaw location in turbine bolts, steam generator tubes, etc and pre metallography.

University of Toronto - ultrasonics on carbon fibre composites and UT inspection of brass bar stock.

Leitz Canada - advice on materials for high radiation fields.

BHWP - Discussions and tests for detection of cracks in ss welds in clad vessels.

AECL-SP - Measurement of pressure tube/calandria tube gap.

3.3 Eddy Current Testing

SLAR - Pressure Tube Calandria Tube Concentricity Monitor

An eddy current technique has been developed to monitor the movement of a pressure tube within its calandria tube. The device uses a minimum of three CIGAR gap probes equally spaced around the pressure tube circumference and produces a signal that reaches a maximum as the tubes are centered along any axis.

A four probe prototype has been delivered for use in noncommissioned reactors at Bruce. Experience with the device showed that the output could easily be distorted by minute amounts of probe tilt caused by the flexing of the pressure tube or probe holder. To overcome this problem for the SLAR project, a floating probe holder was designed and built. The performance capabilities of the three probe device were measured in the laboratory and are currently being tested in the Mark I tool.

CNS - Pressure Tube/Calandria Tube Gap Measurement

Various designs of asymetric bobbin style eddy current probes have been investigated with the hope of measuring larger gap values than is currently possible with the CIGAR based system. A prototype is currently being constructed based on these initial investigations and subsequent research by CRNL for the SLAR gap measurement system. Testing will be carried out to assess the performance of the prototype for dry channel measurement of gap in the NPD reactor.

Temperature Sensitivity of Send Receive Eddy Current Probes

The eddy current probe from the CIGAR gap system is a conventional send-receive design for which an unexpected and significant temperature sensitivity has been measured. The problem has been traced to dimensional changes in the arrangement of coils and, so for potting purposes, an alternate radiation resistant epoxy with less thermal distortion has been specified reducing the temperature sensitivity greatly.

External Garter Spring Detection

A hand held eddy current probe has been developed which can detect the location of garter springs from the outside surface of the calandria tube. The primary application will be for use in experiments conducted on pressure tube mock-ups where access to the calandria tube is available. The probe responds to the small section of garter spring directly beneath it and so it is possible to determine the direction and amount of garter spring tilt. The instrument required is the standard EM-3300.

X-Coil for Garter Spring Detection

A new eddy current coil design has been developed for detecting garter springs. While preliminary testing on a prototype has shown promise, further testing is required to asess its relibility.

Eddy Current Test Methods

A test rig has been built that can accurately and repeatably adjust the concentricity in two axis of pressure tube(PT) and calandria tube(CT) samples. The measurement of the PT/CT spacing is accomplished by electronic dial gauges with computer interfacing capabilities. This allows the response of eddy current probes to PT/CT gap or concentricity to be plotted and evaluated quickly and accurately.

3.4 Miscellaneous

Project Selection/Orangeville Seminar

Besides co-organizing the Metallurgical Research Department Senior Staff Planning Meeting in Orangeville on October 3-5, a research project selection technique has been developed. This approach, called the Market Portfolio Approach, uses ballpark economic estimates of problem area costs. Best, expected and worst case scenarios are developed and costs attached. The results showed that pressure tubes are the dominant problem area for Metallurgy. The Market Portfolio Approach follows typical Industrial Marketing strategy, and looks at the market/problem area before considering product/project.

4.0 GAUGING TECHNIQUES AND INSTRUMENTATION

Pickering NGSA - Fuel Channel Length Measurement Tool

The fuel channel length measurement tool is a device that measures the distance between the faces of endfittings of a drained fuel channel. A manipulative tool equipped with a calibration LoVar measuring tape that is threaded through the channel, has been built and was successfully used in August, 1984, at Pickering A Unit 1. This

measurement used in conjunction with spotface tool measurement readings, provides information about the absolute endshield separation and hence calandria tube elongation.

Pickering NGS-A Mark II Spotface Measurement Tools

The spotface tool is designed for measuring the distance from the end of a fuel channel endfitting to the spotface on the calandria endshield. Two spotface tools, built for Pickering A in early 1981, have been used extensively and have successfully provided spotface measurements on many occasions. Until recently, the tools have been subjected to some operating problems. At Central Nuclear Services' request, three Mark II spotface tools, which are an improved version of the old tools, have been built and successfully used for recent measurements. The strength and ruggedness of these tools have been greatly improved to increase their durability. Use of a commercially available digital readout linear gauge in the new tool has shown more accurate and reliable measurements can be achieved than with the old tools.

Pickering-A Laser Tool

A laser fan beam position measurement tool was developed to assist the Pickering fuel channel shifting program. This tool was used to measure the amount by which a channel was shifted relative to the fan beam reference plane. The tool easily outperformed the commercially available equipment which had previously been used. It reduced the amount of re-shifting of channels that had previously been required. Both the tool and sensor were developed at Research Division.

Pickering-B STEM

The Pickering B Scanning Tool for Elongtion Measurement (STEM) was commissioned at Unit 5 in 1984 and yielded an excellent set of data. Patterned after the Pickering A STEM system, it measures fuel channel length relative to the fuelling machine scan plane using a measurement head mounted in the fuelling machine snout. Some new and additional features include fail safe retract upon loss of power and a 10 cm measurement range.

Bruce-A Laser Tool

A laser tool similar to the Pickering laser tool has been developed for Bruce NGSA for their fuel channel shifting program. Additional features were required. These included increased accuracy, insensitivity to nearby flood lighting, and a remote digital readout in the control room. Most of these and other problems have been solved and the six tools should be shipped sometime in 1985.

Bruce-A HP Turbine Tapbolt Ultrasonic Scanner

A request was received from Central Nuclear Services to investigate the possibility of developing a mechanical tool for ultrasonic (UT) inspection of the tapbolts inside the HP turbine casing during shutdown at Bruce NGSA. It is expected that the UT inspection will not require removal of the turbine casings. The tool will be designed to pass through a 76 mm diameter hole in the turbine casing. The UT inspection head will be located at the hexagon head of the inspected tapbolt, and will be remotely operated outside the turbine casing. Work has commenced on the scanner design and the ultrasonic crack detection investigation.

Bruce-B Scanning Tool For Elongation Measurement (STEM)

The Bruce B Scanning Tools for Elongation Measurement (STEM) were commissioned at Units 5 and 6, and yielded successful preservice baseline measurements. Manufacture of four STEM heads for units 7 and 8 has commenced and all of the long lead time commercial items have been purchased and received. It is anticipated that these STEM units will be ready for site use in mid April 1985.

Bruce-B Endfitting and Feeder Clearance Measurement Tool

Previous endfitting/feeder clearance measurements, made using Go-NoGo gauge bars, were very time consuming and frustrating because of the large number of manipulations required. A new manually operated tool has been designed and fabricated for improving the operating conditions. This simple mechanical tool has been successfully utilized during a recent outage. The station reports that much faster measurements and hence smaller man rem expenditure can be achieved with the new tool than with the gauge bars (approximate ratio of two to one).

III - 1985 WORK PROGRAM OUTLINE

1.0 FRACTURE MECHANICS RESEARCH

Fracture of Zr-Nb Pressure Tube Material With Blisters

Experimental blisters prepared in the laboratory are being grown on small sections of Zr-Nb pressure tube. Currently, tests are being planned to investigate how blisters fracture under monotonic and cyclic loding conditions. Test parameters and blister characteristics will be carefully recorded in an attempt to determine the parameters necessary to induce cracking in the pressure tube matrix beyond a blister.

Fracture Toughness of Hydrided Zr-Nb Pressure Tube Material

A project is planned to systematically determine how variations in hydrogen concentration and hydride morphology affect the fracture behaviour of Zr-2.5wt% Nb pressure tubes. Compact tension specimens fabricated from flattened and stress relieved pressure tube material will be hydrided to several different concentrations and varying proportions of radial and circumferential hydride. Testing over a range of temperatures will give a good indication of how these parameters affect fracture toughness.

Crack Arrest Studies in Zr-Nb Pressure Tube Material

There is a need to investigate the crack arrest properties of Zr-Nb pressure tubes. Very little is known about the behaviour of rapidly propagating cracks, although this information would be valuable for predicting the consequences of a future pressure tube failure.

Experiments will be performed to investigate these properties for Zr-Nb using side-grooved, compact-crack-arrest test specimens as per the proposed ASTM test method for measuring crack arrest fracture toughness. Consideration will be given to the possibility of conducting some burst tests in the future, to further investigate the properties of running cracks.

Fatigue Properties of Temper-Bead Repair Welds

Fatigue crack growth tests on A516 Gr 70 presure vessel steel will be performed to provide material data to be used for the integrity assessment of the heat-affected zone (HAZ) after a non-PWHT weld repair. Compact tension specimens with cracks propagating parallel to the HAZ will be tested to study the effect of HAZ microstructure on crack growth rate.

Repair Weld HAZ Thermal Simulation Study

The Fracture Mechanics Unit and Welding Unit will collaborate on a program to investigate the relationship between heat-affected zone (HAZ) in repair welds and thermally simulated HAZ coupons. The objective of the program is to develop a thermal simulation technique for HAZ microstructure generation which will lead to improved temper-bead weld repair properties through an understanding and optimization of weld repair thermal cycles. The J_{Ic} fracture toughness tests will be performed to assess the viability of using thermally simulated HAZ specimens.

Material Testing to Support Darlington A Heat Transport System Piping Analysis

A joint project between Mechanical Design, D&D and Research has been initiated to demonstrate the safety of Darlington A primary heat transport system using a tearing modulus approach. An extensive material test program will be conducted to determine J-T resistance curves of A106B piping steel and associated welds at various temperatures. This information will be used for the structural analysis of the piping system. The unit will also provide assistance with the analytical aspect of the project.

R&D in Linear Elastic Fracture Mechanics

Refine existing computer programs for elastic three dimensional finite element stress and fracture analysis.

Perform a fracture analysis of postulated cracks in a Darlington steam generator (this is a joint Mechanical Design/Research CANDEV funded project).

Continue to maintain and update Code acceptable flaw evaluation procedures for pressure retaining components and if possible develop a "personal" computer system to perform Section XI evaluations for use by others in Ontario Hydro.

Failure Assessment Diagram (R-6 Approach) Evaluation

The 'Failure Assessment Diagram (FAD)' software (an elastic-plastic fracture mechanics evaluation method, developed by CEGB and further improved by B&W) will be introduced to the FM Unit. In order to develop an EPFM flaw evaluation capability within the Unit, analyses of various defect models in the pressure vessel and piping will be performed.

Stress Analysis of Pressure Tube Hydride Blisters

Efforts on finite element analysis of pressure tube hydride blisters will continue. A two-dimensional axi-symmetric as well as three-dimensional model will be used coupled with a realistic hydride concentration distribution to determine local stress near a blister. Also, crack driving forces at crack tips near blister/matrix interface will be studied numerically to investigate the extent of blister expansion. Experimental verification on the numerical model will also be attempted.

2.0 NONDESTRUCTIVE INSPECTION RESEARCH AND DEVELOPMENT

CIGAR

CIGAR acceptance tests will be conducted in February and, if all goes well, the system will be sent to Bruce B Unit 8 for plant commissioning and to perform mandatory preservice inspections. The first planned use of the system on an active reactor is at Bruce A in mid 1985.

CIGARette

Improvements in the wall thickness gauging system are being made. Also, a containment cable penetration may be constructed. The system is being kept in readiness should its use be required on an emergency basis.

NILOCS/NIMOCC

Vibration signature analysis and generalized cross correlation methods will be further developed and their usefulness for noninvasive location of channel spacers will be assessed.

CIRENE - Pressure Tube Inspection System

It is anticipated that assistance will be provided to NBV in preparing a proposal for supplying a pressure tube inspection system to CIRENE. Follow up work for system reconfiguration is also expected.

Robotic Scanning System

Interfacing of the PUMA robot with the Sperry computers will be completed and the ultrasonic software interface capabilities will be expanded.

Laboratory Ultrasonic Scanning Systems

Conversion of the laboratory scanning systems from the Apple computer to Sperry computer control will allow greater speed, scan size and signal amplitude resolution.

Acoustic Emission

Pickering A - Assistance will be provided in locating closure or Grayloc connection leaks on Unit 4 in early 1985. Equipment for on-line leak detection developed by the Unit and successfully used on previous occasions will be used.

Lakeview TGS - Monitoring of acoustic emission from economizer headers will continue. The opportunity will be used to evaluate new equipment and techniques.

A robot system for leak detection using airborne acoustic emission has been proposed. In this system, an ultrasonic microphone is angled in two degrees of freedom to scan an area. If accepted, the concept will first be tested using the section's six axis robot. At present, manual scans using the ultrasonic microphone with reflector have shown considerable promise, but are plagued with problems of poor repeatability.

Ultrasonic Testing

SLAR - Work on the fast scan blister probe will be completed and the computer and data acquisition system will be built and tested.

Nuclear Waste - A robot controlled waterjet coupled ultrasonic inspection of titanium diffusion bonds will be evaluated. An assessment of the effects of candidate weld material on shearwave propagation will be performed.

CNS - A procedure for detecting cracking in turbine tap bolts will be developed.

CNS - Work to increase our understanding of the ultrasonic inspection of pressure tube blisters will be pursued.

CNS - The development of improved Pickering steam generator manway inspection procedures will continue with improvement of contact focussed transducers and design and fabrication of an improved scanning system.

CNS - A program to verify the effectiveness of in-service inspection procedures for PHT components inspection is planned. Test samples with induced real defects will be made and a round robin test organized.

CNS - Feasibility of developing an in-house capability for inspection of LP steam turbine rotor disks will be studied. If feasible, the development of a computer based system would be pursued. This would likely include special purpose manipulator system and ultrasonic data acquisition, storage and presentation.

Research - Investigation of very high frequency ultrasonics for applications such as pressure tube hydride detection will continue. Improved probes and equipment will be obtained and tested.

Research - A single skip CIGAR head will be fabricated and its advantages evaluated.

Research - Further investigation of the crack tip diffraction method of crack depth measurements will take place. Signal averaging or SAFT techniques may be tried to improve performance.

Research - Computer modelling to develop probability of detection (POD) predictions for pressure tube inspection and other investigations will be performed.

Eddy Current

CNS - Pressure Tube/Calandria Tube Gap Measurement - The CIGAR and CIGARette gap systems will continue to be supported and improved. Work will include dealing with pressure tube resistivity variations and investigating in-channel methods of verifying equipment operation.

CNS - Pressure Tube Gap Measurement in NPD - A prototype is currently being prepared which should not require wall thickness compensation and should have greater range than existing systems. Exact performance specifications will be determined and an inspection of NPD will be discussed in 1985.

CNS - Study of Errors in Steam Generator Inspections - A parametric error study of current steam genertaor inspection methods utilizing computerized data acquisition and analysis methods is planned.

Research - Eddy Current Data Handling on a Sperry Personal Computer - Various programs will be developed to acquire, manipulate and analyze laboratory data using methods specific to eddy current testing.

Research - Computer Modelling of Eddy Current Probes - Computer simulation models will be modified and enhanced for use on available systems in order to better direct and confirm experimental laboratory work.

Research - A second prototype of the X-coil for garter spring detection will be completed in 1985. It will be tested on a pressure tube with a simulated diameter constriction. There is a possibility that this coil arrangement will give a better signal to noise ratio without the need for a multifrequency instrument.

SLAR - Pressure Tube/Calandria Tube Concentricity Monitor - Further involvement with the monitor is possible if it is accepted for use in the final design of the SLAR tool.

CIRENE - Reactor Inspection - A gap and garter spring inpection has been proposed for an experimental vertical reactor under construction in Italy.

Gauging Techniques and Instrumentation

Bruce B - Scanning Tool for Elongation Measurement (STEM) - Four STEM heads will be manufactured and tested for Bruce B Units 7 and 8.

Pickering/Bruce NGS - Digital linear gauges for Channel Elongation Measurements - 10 (or more) digital linear gauges will be devised and manufactured for various elongation measurement tools for different stations.

Darlington NGS - Channel Elongation Measurement Tools - Possibility of using the current channel elongation measurement tools, such as spotface tools and STEM devices, in Darlington NGS will be investigated.

Pickering/Bruce NGS - Electronic Distance Measurement (EDM) device for fuel channel length - development work on the EDM technique will be pursued.

Bruce NGSA - Tapbolt Ultrasonic (UT) Scanner - Development work on the tapbolt UT scanner will proceed with full scale mockup tests.

IV - SUPPORT TO THE EXTERNAL COMMUNITY

The influx of new ideas is essential to any organization if it is to remain successful. These ideas may be triggered by presentations or discussions at conferences, or conversation with contacts in external organizations having similar interests. New ideas are often brought in by new staff, but the economic situation in which we find ourselves has effectively eliminated this source.

Often, our contacts in external organizations have been forged through meetings at conferences. The forum of the technical conference has another valuable purpose in that the presentations made by ourselves are subjected to rigorous peer review, and thus give us some sense of 'being on the right track'. It is hoped that our presentations trigger innovation in those that listen to our accomplishments.

In addition to our profile at technical gatherings, it is felt that the Corporation, for its own benefit, must nurture relationships with academic institutions such that educators and students become aware of our needs and problems. It is the new graduates that represent the future of our organization. Also, such contact provides an accurate glimpse of Ontario Hydro perhaps quite different than that promoted in the popular media. To this end, the Nondestructive and Fracture Evaluation Section has developed close working relationships with a number of academic institutions.

University of Toronto

In the Mechanical Engineering Department, a number of final year students requested the opportunity to work on thesis topics in an industrial setting rather than the university's laboratories. This is advantageous to the students as they set to work on real problems of a research nature and the equipment available is modern and comprehensive. The professor is assured that the appropriate expertise and guidance is available. Ontario Hydro benefits directly as we are able to work on valuable projects which otherwise would not be undertaken, and with minimum cost.

At the present, we have students working on fracture toughness measurement of turbine rotor steel, determination of hydride platelet population and orientation using high frequency ultrasound, and investigation of defect sizing using crack-tip diffraction of ultrasound.

University of Manitoba

The Department of Mechanical Engineering has a PRAI grant awarded by the Natural Sciences and Engineering Research Council (NSERC). Essentially, the University will develop acoustic emission instrumentation using a new approach. Our responsibilities include

monitoring the project on behalf of NSERC, providing information and recommendations of a technical nature to UofM, and making available an industrial test site (Lakeview GS).

Mohawk College and CSNDT Foundation

The Corporation benefits from the courses at Mohawk in that they meet our needs in producing technician/technologists for our nuclear inspection programs. In turn, members of the Section have assisted in teaching courses in specialized areas.

Viatec Resource Systems

Research Division has an information sharing agreement with Viatec Resource Systems. Viatec has stationed an engineer with ND&FE Section to develop expertise in acoustic emission technology. In turn, the presence of this engineer relieves some of the pressure on our almost non-existent manpower resources in this area.

Canadian General Standards Board

A member of the section represents the interests of the Corporation on the committee dealing with the certification of NDT personnel.

V - RESOURCES

Resourcing our 1984 work programs presented a monumental problem. This situation has not changed as we begin 1985.

In the Fracture Mechanics Unit, the departure of Dr. Pauline Davies created quite a vacuum which we were unable to fill until mid-December.

The resource base in the Nondestructive and Fracture Evaluation Unit is in a critical state. It was necessary to secure the assistance of two contract technicians to assist in our ultrasonics laboratory and with the electronic hardware associated with CIGAR. Unfortunately, employment of people in this capacity is no longer an option. The Presidents Advisory Committee, through the four fuel channel working groups, identified acoustic emission as a key technology area. Although expertise in this discipline still exists in the Section, no manpower is available for carrying out this important work. The high priority work associated with noninvasive location of garter springs had to be resourced by contracting two external consultants plus support of an engineer from Electrical Research Department. Although this may meet short term goals, it is most unsatisfactory in a research setting as we do not gain the benefit of the learning process

in the development of the required expertise. In this mode of operation there can be no spin-off benefits. The current indication is that this resource deficiency will be rectified in 1985.

In all, we were able to accomplish only 70% of our OM&A work program, plus some client requests could not be addressed. The shortfall represented approximately 4 man-years in 1984.

In priority order, the needs of the Section are:

i. Engineer - Acoustic Emission
ii. Technician/Technologist - Ultrasonics
iii. Junior Engineer - Ultrasonics

VI - SUMMARY

Our 1984 work program plan, which was set before the 1st August 1983 pressure tube failure, called for us to spend K$1040 on Research Division funded projects, mostly in the mid and long term ranges. All of this was in the nuclear generation program. In reality, our program was reduced to K$683 or about 66% of that planned due to our involvement in post G16 work.

Progress on the CIGAR project has, at times, been frustrating. Early "borrowing" of critical components for CIGARette essentially stopped work and initial efforts to correct individual flaws in the externally developed drive software simply created new problems elsewhere in the program. This latter situation was only resolved after a massive, systematic attack on the entire software package. At year end, CIGAR was rapidly approaching completion with planned commissioning tests at Bruce Unit 8 in spring 1985 followed by an actual in-service inspection operation on Bruce Unit 4. Already work is underway on improvements over reference design.

Both the Fracture Mechanics and Nondestructive Evaluation Units were heavily involved in the pressure tube blister problem. In Fracture Mechanics, interest focussed on the stress fields associated with blisters, particularly the finite element modelling technique. In Nondestructive Evaluation, prime interest was the detection and sizing of blisters using ultrasound. Another area of common interest was the Pickering steam generator flaws. Here, the NDE unit was concerned with determination of defect sizes whilst the FM unit was involved in an ASME Section XI analysis of defect severity and the implications on continued operation of the boilers.

Other examples of involvement in fracture mechanics analytical methods include, evaluation of cast iron nuclear waste containers, stress intensity factor computation related to pressure tubes, structural integrity evaluation of Bruce A pump flywheel keyways and fatigue evaluation of Bruce A generator end rings.

The fracture mechanics laboratory was, perhaps, less active with externally funded projects than previous years. However, significant effort was expended in the design and evaluation of double torsion fracture toughness tests on Zr-Nb material. The laboratory maintained very close liaison with the pressure tube materials programs conducted at Whiteshell, Chalk River and within the Materials Integrity Project of Research Division. This included participation in round robin tests. Another round robin test was conducted through the auspices of ASTM. Here interest was in the determination of crack arrest toughness in ferritic materials.

Another laboratory project, small but worthy of note, was the production of eddy current standards consisting of circumferential fatigue cracks in steam generator tube specimens.

There is no question that the major work in the Nondestructive Evaluation Unit centered around the CIGARette inspections at Pickering, evaluation of inspection results, development of a reliable technique which would indicate pressure tube/calandria tube spacing, and development of ultrasonic techniques for blister detection and mapping. Later in the year, involvement in the SLAR project commenced in earnest. Here our input has been into the overall mechanical concept, the detection of blisters in a single axial transverse, the detection of pressure tube/calandria tube concentricity and automated pressure tube wall thickness measurement in support of Chalk River's development of a gap sensitive eddy current probe.

The NonInvasive Location of Channel Spacers (NILOCS) and NonInvasive Monitoring of Channel Condition (NIMOCC) projects are administered by a member of the ND&FE Section. The Section also has significant direct technical involvement in the work being undertaken in the acoustic emission and generalized cross correlation methods. This work is of a research nature in that it is the development of new technology yet it is also very applied in that the application is specific with well quantified economic benefits. This mixture of research and application, at times, creates conflict.

It is well recognized that robotics will play an important role in future nondestructive testing endeavours. Automated inspection can potentially improve spatial correlation of data reduce test time, increase the scope of inspection and enable precision work to be done in hazardous environments. In this area, the Section has embarked on a comprehensive program of automation, with some laboratory and field applications already realized.

Nuclear generating stations still remain a new venture to Ontario Hydro and other utilities in that we have not taken the post Pickering 1 & 2 reactor designs through an entire life cycle. Designers and operators need precise dimensional measurements to input into design equations and to predict the likelihood of required modifications. The involvement here has included fuel channel length measurement tools, spotface tools, channel shifting measurement using a fan beam laser, scanning tool for channel elongation measurement, endfitting and feeder clearance measurement tools.

In 1985 it is anticipated that our role in the CIGAR project will mature into developing improvements, especially the facility of adding new capabilities. Some 'safeguard' work will be performed in support of CIGARette, but the anticipated success of CIGAR will, for the most part, obsolete the CIGARette equipment. There is a strong possibility that the Section becomes involved in a second CIGAR - this time for the Italian vertical pressure tube reactor at CIRENE. Projects related to SLAR are expected to approach completion and it is expected that the year will mark a major turning point with the NILOCS/NIMOCC projects. It is recognized that both of these work areas are 'high risk' - we may not be able to realize our objectives - but the potential pay-off is so enormous that we cannot afford not to do the work. It is regretted that the manner in which this important project is being resourced effectively precludes spin-off benefits.

It is felt that research into "advanced" ultrasonic techniques is urgently required. It is essential that we must seek to answer the perennial question, 'how big is the defect?'. Until we can do this, the fracture mechanics engineers must be grossly conservative.

Work in eddy current technology is predicted to maintain its emphasis on fuel channels but it must be recognized that we need to address some of the concerns expressed by those responsible for steam generator inspection.

There will be continual demand for precise spatial measurement devices and involvement is anticipated to remain about constant. Also expected to remain constant, or perhaps increase to some degree is our involvement with robotic and automated systems.

In 1985 we look forward to establishing the NDE Center for the benefit of the Corporation as a whole. It is hoped that the Center will enable a much more free interchange between researchers, designers and operators.

1983 and 1984 witnessed a coming of age of fracture mechanics. Direct client requests for work increased both in quantity and quality. In the coming year it is anticipated that there will be a great emphasis on pressure tube materials, both from the analytical and experimental aspects. It is planned to perform material testing on pressure tube

samples containing blisters in order to delineate the parameters necessary to induce the familiar cracking in blisters. Also in the laboratory, work is planned to determine the effect of hydrogen and hydride morphology on fracture toughness of Zr-Nb pressure tube material. The behaviour of rapidly propagating cracks in pressure tube material will also be investigated. Stress analysis of blisters using a finite element approach will continue.

Outside of nuclear reactor materials, it is planned to perform fatigue crack growth testing on A516 GR 70 pressure vessel steel subjected to temper bead repair welds. J_{Ic} fracture toughness tests will also be performed on repair weld material, emphasizing the heat affected zone. An extensive materials testing program will be initiated in support of Darlington NGS. This will include determination of J-T resistance curves for A106 piping steel.

In analytical fracture mechanics, it is planned to refine existing computational capabilities in the area of elastic three dimensional finite element stress and fracture analysis. The Fracture Mechanics Unit has acquired access to a computer code related to the 'failure assessment diagram' (R-6 approach). This was developed by CEGB and modified by Babcock-Wilcox.

In all, the Section looks forward to a very diverse work program in 1985.

ACKNOWLEDGEMENT

Both the accomplishments during 1984 and the written descriptions of them as they appear in this report are the work of all the Section staff. Their individual contributions to the overall work program for the Section and the contents of this report are most gratefully acknowledged.

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NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION
CONFERENCE PRESENTATIONS AND PUBLICATIONS - 1984

1.0 CONFERENCE PRESENTATIONS

B. Mukherjee, M.L. Vanderglas and D.M. McCluskey, "Toughness Measurement and Structural Integrity Consideration of a Pressure Vessel", Fifth International Conference on Pressure Vessel Technology, San Francisco, Sept 1984.

B. Mukherjee and M.L. Vanderglas, "Integrity Evaluation of Power Plant Components By Fracture Mechanics", Sixth International Conference on Fracture, New Delhi, India, December 4-10, 1984.

Y.J. Kim and J.W. Prince, "Integrity Evaluation of Temper Bead Weld Repairs in Pressure Vessels", 1984 ASME Pressure Vessel and Piping Conference, San Antonio, Texas, June 17-21, 1984.

A.C. Wallace, "The Development of Curved Fracture Toughness Specimens for Predicting Crack Growth in CANDU Reactor Pressure Tubes", Eleventh Canadian Fracture Conference, Ottawa, June 14-15, 1984.

P.H. Davies and C.P. Stearns, "Fracture Toughness of Zircaloy-2 Pressure Tube Material with Radial Hydrides Using DC Potential Drop", 17th National Symposium on Fracture Mechanics, Albany, N.Y., August 7-9, 1984.

J.A. Baron, "Acoustic Emission of Man-Lift Devices", 5th Canadian Conference on NDT, Toronto, Ontario Oct 28-31, 1984.

M.D.C. Moles, "Residual Life of Thermal Plant Boiler Tubing ... An EMAT Device for Measuring Tube Wall Thickness", CEA Fall Session, Calgary, Oct 14-16, 1984.

J.H. Sedo, "Wet Channel Measurement of Pressure Tube to Calandria Tube Spacing in Ontario Hydro's Nuclear Reactors", 5th Canadian Conference on NDT, Toronto, Ontario, Oct 28-31, 1984.

M.D.C. Moles, "Wet Channel Inspection Systems for CANDU Nuclear Reactors ... CIGAR and CIGARette", 5th Canadian Conference on NDT, Toronto, Ontario, Oct 30, 1984.

J.A. Baron, M.P. Dolbey, D.V. Leemans, "An Eddy Current Technique to Estimate the Dimensions of Crevice Corrosion Pits", Symposium: Nondestructive Testing and Electrochemical Methods of Monitoring Corrosion in Industrial Plants, Montreal, May 22-24, 1984.

E. de Buda, W.K. Chan, M.D.C. Moles, "A Robotic Scanning System for Ultrasonic Inspection", Conference on Robotics and Remote Handling in the Nuclear Industry, Toronto, Ontario, September 23-27, 1984.

2.0 PAPERS PUBLISHED

Y.J. Kim, B. Mukherjee and D.W. Carpenter, "Effect of Hydrogen on Crack Initiation and Growth in 18 Mn 4 Cr Steel", ASTM STP 868, 1985.

B. Mukherjee, M.L. Vanderglas, and D.M. McCluskey, "Toughness Measurement and Integrity Consideration of a Pressure Vessel", Proceedings of the Fifth International Conference on Pressure Vessel Technology", Sept 9-14, 1984, ASME, pp 1020-1033.

B. Mukherjee and M.L. Vanderglas, "Integrity Evaluation of Power Plant Components by Fracture Mechanics", Advances in Fracture Research, Volume 5 - Dynamic Fracture, Experimental Techniques Engineering Application, pp 3485-3498, Proceedings of the 6th International Conference on Fracture, December 1984, Pergamon Press.

A.W. Wallace, "The Development of Curved Fracture Toughness Specimens for Predicting Crack Growth in CANDU Reactor Pressure Tubes", Time Dependent Fracture, Proceedings of the Eleventh Canadian Fracture Conference, June 14-15, 1984, Martinus Nijhoff, Publishers.

M.D.C. Moles, A.L. Allen "Tandem Probe Ultrasonic Measurement of Cracks in Economizer Inlet Header Sections", Materials Evaluation, April 1984, Special Edition on Flaw Characterization.

P.H. Davies, "An Elastic-Plastic Fracture Mechanics Study of Crack Initiation in 316 Stainless Steel", ASTM, Special Technical Publication 803, Vol II, pp 611-631.

J.A. Baron, M.P. Dolbey & D.V. Leemans, "An Eddy Current Technique to Estimate the Dimensions of Crevice Corrosion Pits, ASTM Special Technical Publication.

3.0 PAPERS SUBMITTED FOR PUBLICATION

Y.J. Kim and M.L. Vanderglas, "Numerical Analysis of Hydride Blisters in Pressure Tubes", 8th International Conference on Structural Mechanics in Reactor Technology, Brussels, Belgium, 1985.

P.H. Davies and C.P. Stearns, "Axial Fracture Toughness of Zr-2.5 Nb Pressure Tube Material", Fractura Mechanics, Sixteenth Symposium, ASTM STP 868, M.F. Kanninen and A.T. Hopper, Eds, American Society for Testing & Materials, 1985.

4.0 ABSTRACTS SUBMITTED FOR CONFERENCE PRESENTATION

M.D.C. Moles and J.W. Huggins, "Ultrasonic Inspection of Blisters in Pressure Tubes", Fuel Channel Technology Seminar, April 1985. Oakville, Ontario.

J.H. Sedo and F.L. Sharp, "Eddy Current Detection of Garter Springs", Fuel Channel Technology Seminar, April 1985. Oakville, Ontario.

M.D.C. Moles and A.L. Allen, "Ultrasonic Inspection of Titanium Diffusion Bonds for Nuclear Used Fuel Containers", 11th World Conference on Nondestructive Testing, Las Vegas, Nevada, Nov 3-8, 1985.

Y.J. Kim and M.L. Vanderglas, "A Numerical Modelling Technique of Hydride Blisters in Pressure Tubes", Tenth Canadian Congress of Applied Mechanics, University of Western Ontario, London, Ontario, June 1985.

B. Mukherjee and D. McCluskey, "Measurement of Crack Arrest Fracture Toughness of 7075-T6 Aluminum Alloy", 18th National Symposium on Fracture Mechanics, June 1985, Boulder, Colorado.

A.C. Wallace and D.K. Rodgers, "Crack Initiation at Blisters", Fuel Channel Technology Seminar, April 23-25, 1985, Oakville, Ontario.

Y.J. Kim and M.L. Vanderglas, "Numerical Analysis of Hydride Blisters in Pressure Tubes", 8th International Conference on Structural Mechanics in Reactor Technology, Brussels, Belgium, 1985.

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